Effects of Water-Rock Interaction of Unsaturated Flow in Heterogeneous Fractured Rock

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RESEARCH OBJECTIVES

Evaluation of coupled thermal, hydrological, and chemical processes associated with the proposed high-level nuclear waste repository at Yucca Mountain, Nevada, requires consideration of the effects of permeability heterogeneity on reaction-transport processes. The primary objective of this work is to examine the relationship of fracture flow and fracture-matrix interaction to permeability and capillary pressure modification during mineral precipitation and dissolution in unsaturated fractured tuff under boiling conditions.

APPROACH

In this analysis, we relate the reactive surface area to the fracture-matrix interaction area, based on a modified form of the Active Fracture Model for flow in unsaturated fractured rock. In most experimental and natural systems, permeability reductions to values near zero occur at porosities significantly greater than zero. This generally is the result of mineral precipitation preferentially closing the narrower interconnecting apertures. The hydraulic aperture, calculated from the fracture spacing and permeability (as determined through air-permeability measurements) assuming a cubic law relation, was used to develop a much stronger relationship between permeability and porosity. Based on air-permeability measurements, 2-D heterogeneous fracture permeability fields were generated having a range of four orders of magnitude. Reaction-transport simulations were performed using TOUGHREACT, which included coupling between heat, water, and vapor flow; aqueous and gaseous species transport; and kinetic and equilibrium mineral-water reactions. Changes in unsaturated flow take place through coupling of porosity, permeability, and capillary pressure to mineral precipitation/dissolution.

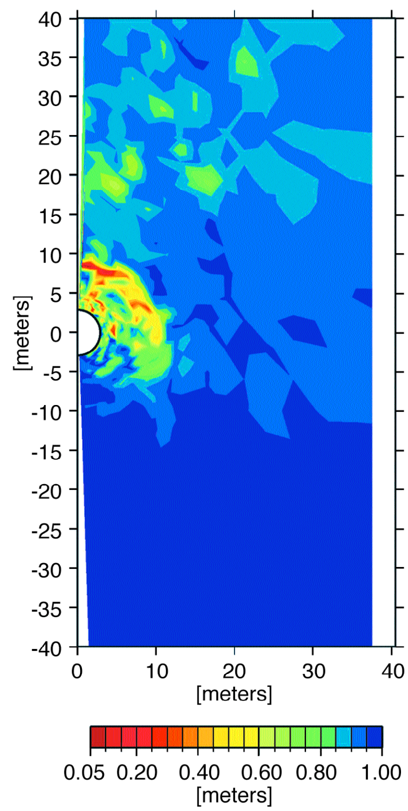

Figure 1. Ratio of fracture permeability at 20,000 years to the initial value

ACCOMPLISHMENTS

Simulations demonstrated that in addition to thermodynamic and geochemical parameters, the extent of mineral-water reaction is a function of the fluid flux and the liquid saturation. Liquid saturations, which control reactive surface areas, and fluxes are strongly tied to the permeability and capillary properties. At the edge of the boiling front, mineral precipitation is driven by a combination of mineral-water-reactions and evaporative concentration. The net effect of these processes over 20,000 years is a reduction in permeability that is most pronounced in areas of initially low permeability but high liquid fluxes and saturation (Figure 1). The distribution of permeability changes is, however, a combined effect of different minerals precipitating in varying patterns. Amorphous silica, calcite, and gypsum precipitate by evaporative concentration at the boiling front, resulting in a narrow zone of reduced permeability. Calcite also precipitates by degassing of CO_2 and heating of percolating fracture water from the surface, thus leading to abundant precipitation well above the boiling zone.

SIGNIFICANCE OF FINDINGS

Modeling of water-rock interaction in boiling, unsaturated, heterogeneous fractured rock exemplifies the strong feed-backs between water-rock interaction and unsaturated flow. In particular, increased liquid saturation, as a result of higher capillary pressures in smaller aperture fractures, leads to increased rates of reaction and further reductions in permeability. This work indicates that the evolution of preferential flow paths in unsaturated systems undergoing water-rock interaction may progress from the smaller features to the larger ones, in contrast to saturated systems that tend to start with the most permeable features.

RELATED PUBLICATION

Sonnenthal, E., N. Spycher, and T. Xu, Linking reaction, transport, and hydrological parameters in unsaturated fractured rock: TOUGHREACT implementation and application. Proceedings of the TOUGH Symposium, Berkeley, California, May 12-14, 2003.

ACKNOWLEDGMENTS

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